CCD Instrumental Signatures

Gary Bernstein (UPenn) & Andrei Nomerotski (BNL)

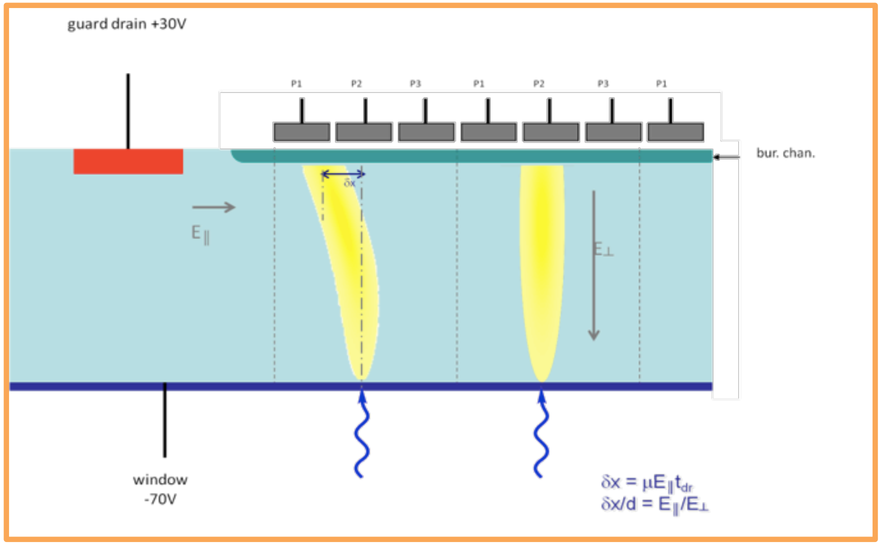
DES-LSST meeting, Fermilab, 24 March 2014

What’s the problem with thick CCDs?

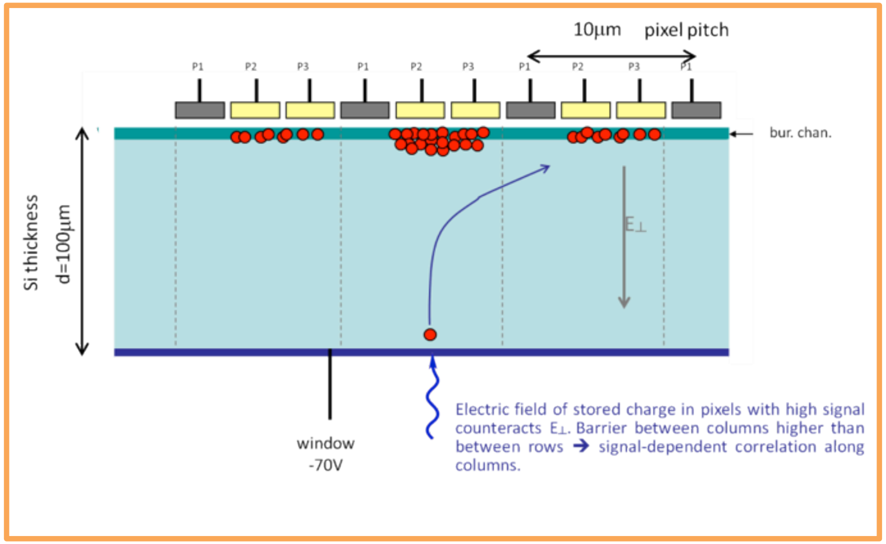
Electrostatics in semiconductor

Electric field lines inside CCD are not straight →
pixels change their size and shape

Static : edge effects, tree-rings



“Dynamic” : brighter-fatter effect

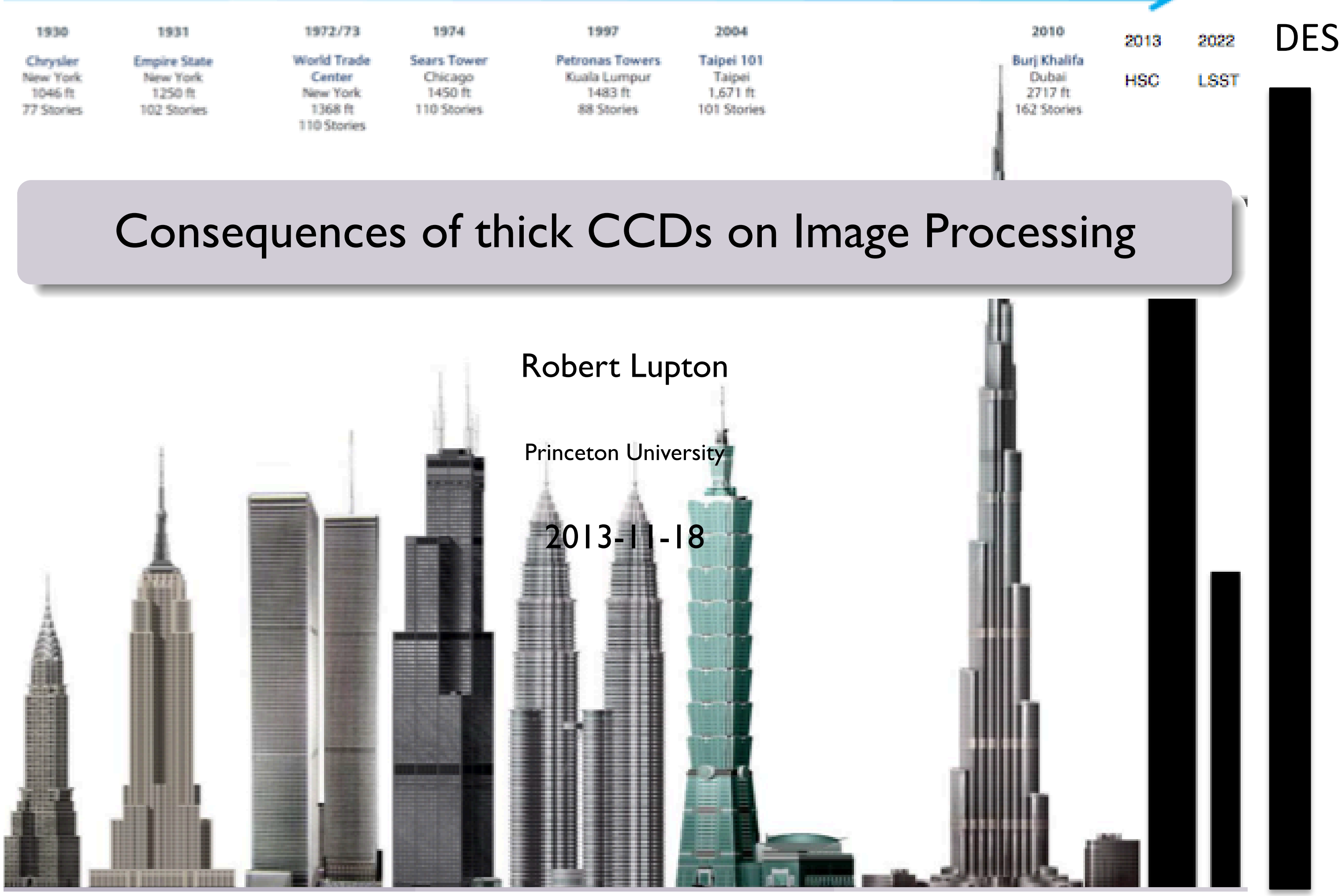


Consequences of thick CCDs on Image Processing

Robert Lupton

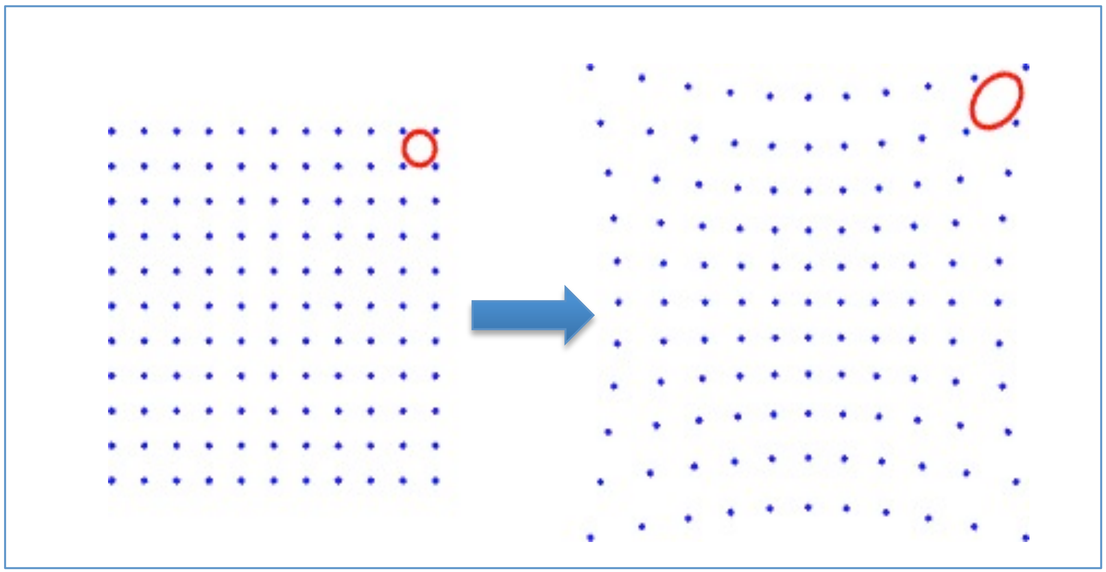
Princeton University

2013-11-18



Pixels are skyscrapers

Astrometry is mapping from pixel coordinates to the sky



Jarvis

$$J = \begin{pmatrix} \frac{du}{dx} & \frac{du}{dy} \\ \frac{dv}{dx} & \frac{dv}{dy} \end{pmatrix} = \frac{1+\mu}{\sqrt{1-g^2}} \begin{pmatrix} 1-g_1 & -g_2 \\ -g_2 & 1+g_1 \end{pmatrix} \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

Need to account for magnification, shear and rotation

Workshop “Precision Astronomy with Fully Depleted CCDs” at BNL 18-19 Nov 2013

Goals:

- Bring together people working on instruments, algorithms and science
- Bring together current and future experiments

- Over 70 participants from 32 institutions, 14 from outside the US
- 20 talks and 8 posters →Proceedings in JINST

Workshop "Precision Astronomy with Fully Depleted CCDs" at BNL 18-19 Nov 2013

Formed a working group (Astier, Bernstein, Jarvis, Lupton, Magnier, Miyazaki, Nomerotski, O'Connor, Peterson, Stubbs)

- Communications between experiments
- Bridging sensors, algorithms and science
- Regular general phone meetings → another workshop in fall 2014

- Encouraging that one can understand these effects from the telescope data

  Gary's talk: DES data

- But better to study them under controlled conditions of the lab BEFORE the detector go to telescope

  Andrei's talk: LSST sensor testing and simulations

Andrei's talk Outline

- Instrumental effect related to sensors
  - Brighter Fatter, tree rings and edge effects

- How we plan to address this in LSST
  - Lab measurements
  - Simulations of sensor effects
  - Systematics due to sensor effects

LSST Sensors

Science sensors

- Good prototypes from e2v and ITL; First articles ordering in progress

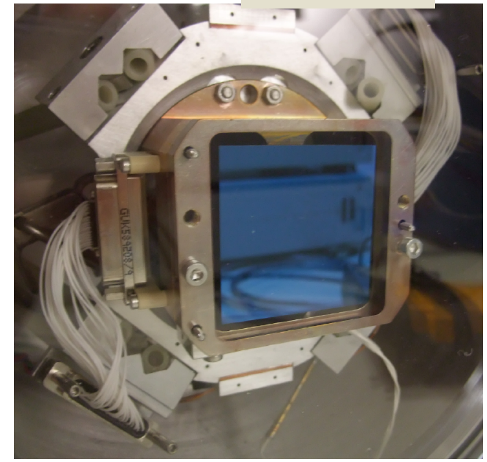
Production in 2015 - 2019

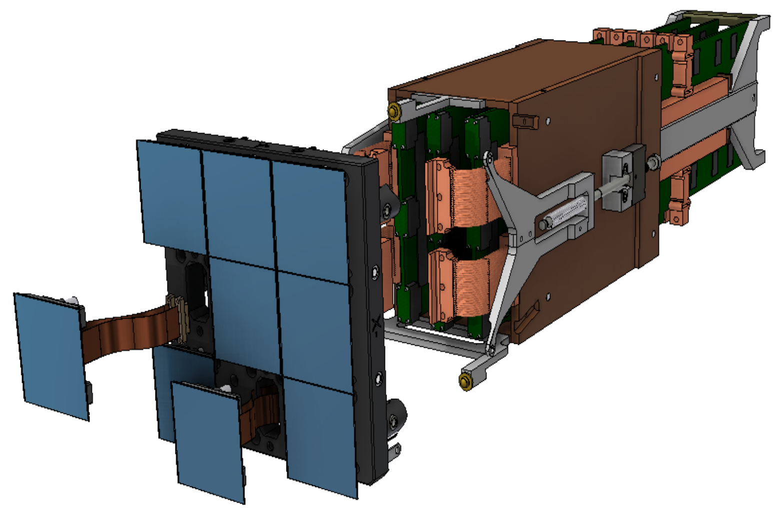
- Sensor acceptance testing and raft assembly in BNL and LPNHE (Paris)
- Raft integration in camera cryostat at SLAC

Testing labs: careful characterization of sensors (beyond acceptance testing)

- BNL (includes raft characterization); Harvard; LPNHE; UC Davis

CCD250

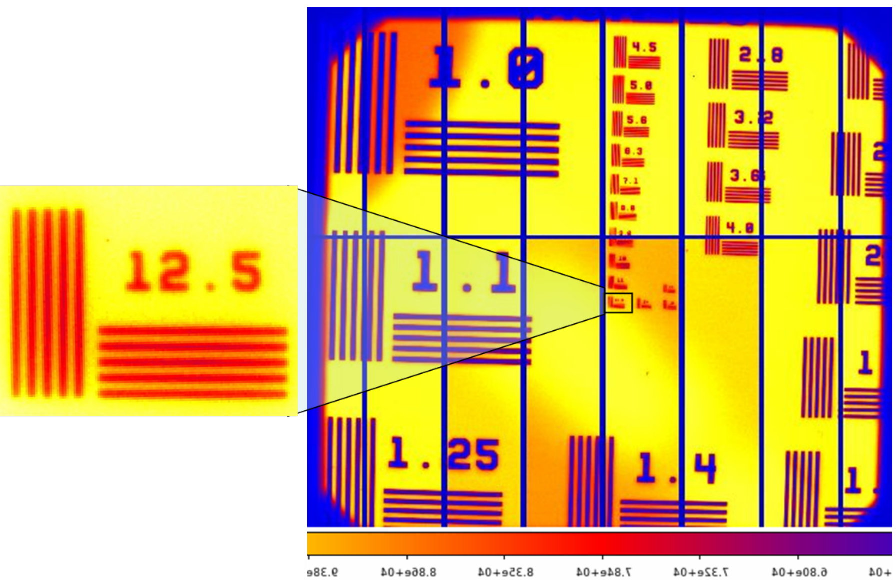




Raft Tower Module

Fast progress towards LSST raft

- Raft test cryostat with full signal chain in operation in BNL since Feb 2014
  - So far a single CCD
- Raft is a 9-CCD, 144 Mpix camera
  - planned as LSST Commissioning Camera in 2019-2020



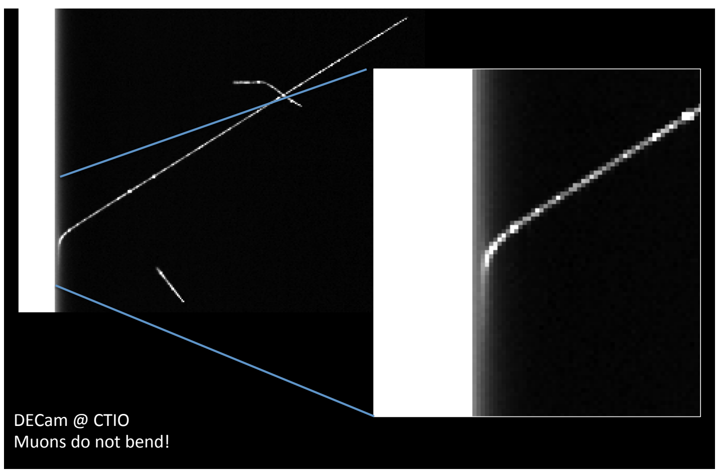
Single-CCD image from Raft Test Cryostat

LSST BNL team

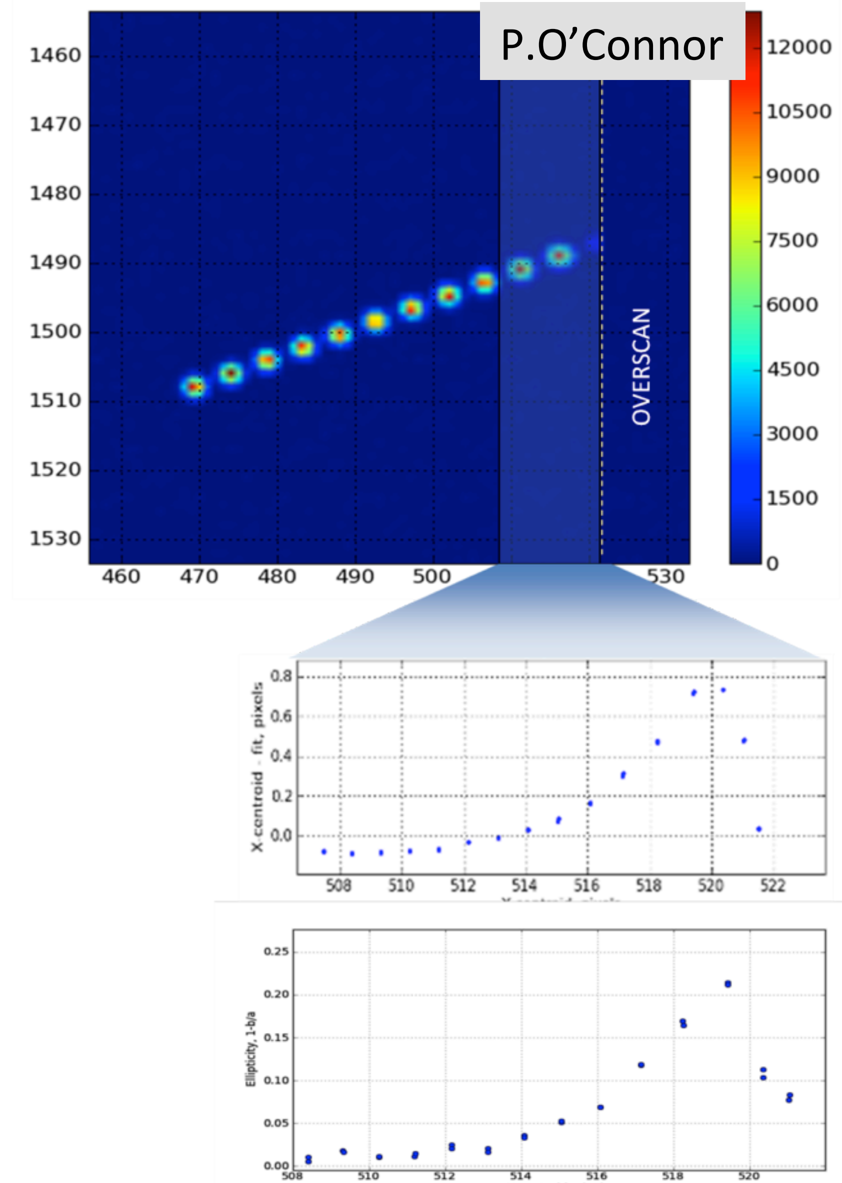
Edge Effects in CCDs

- On the egde:
  - Non-linearity up to 50%
  - Ellipticity up to 20%

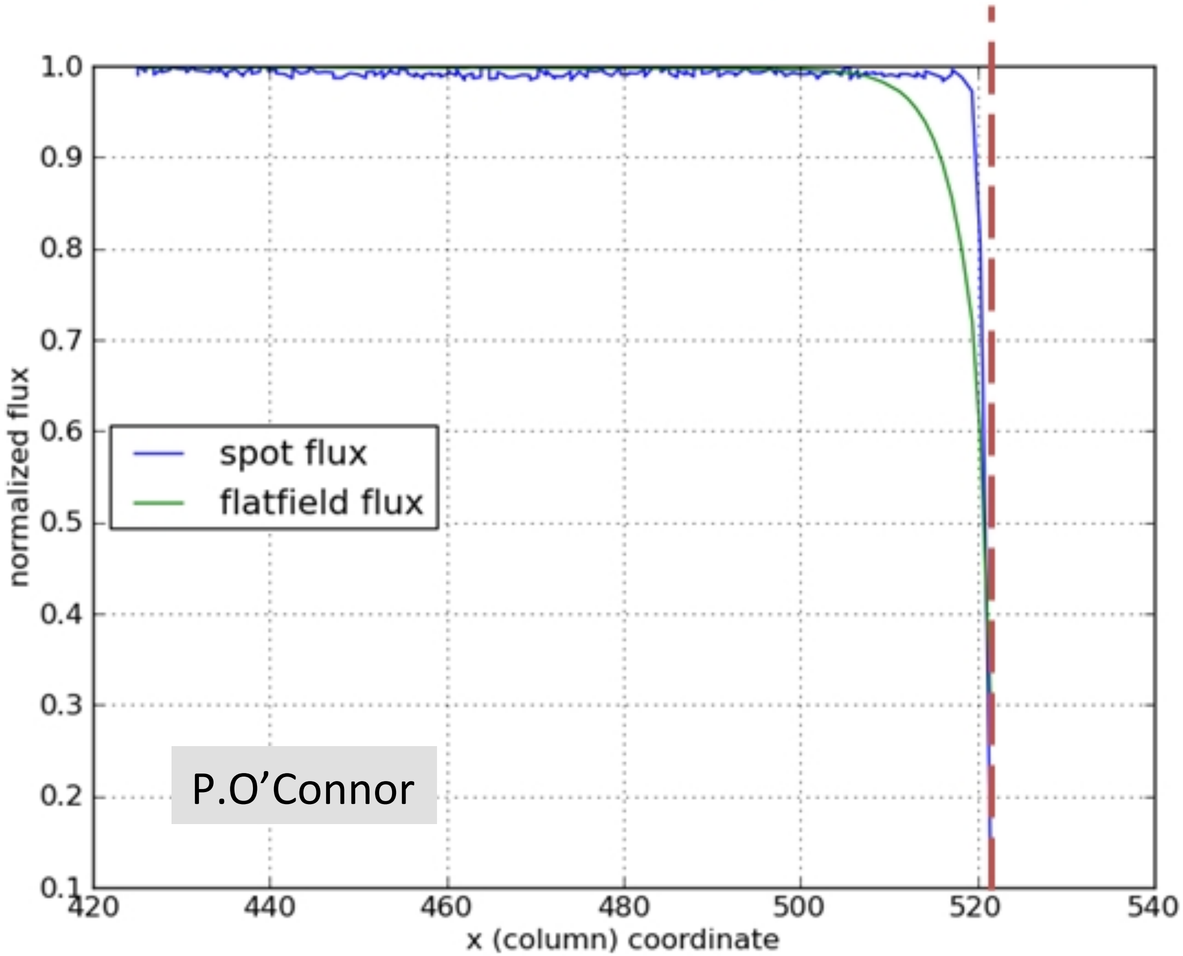
- DES saw similar effects
  - Also for cosmic muons



J.Estrada



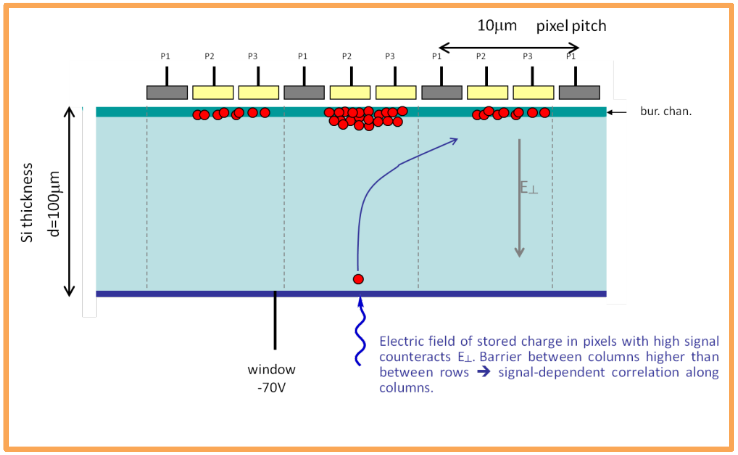
Spot flux does not trace flatfield flux

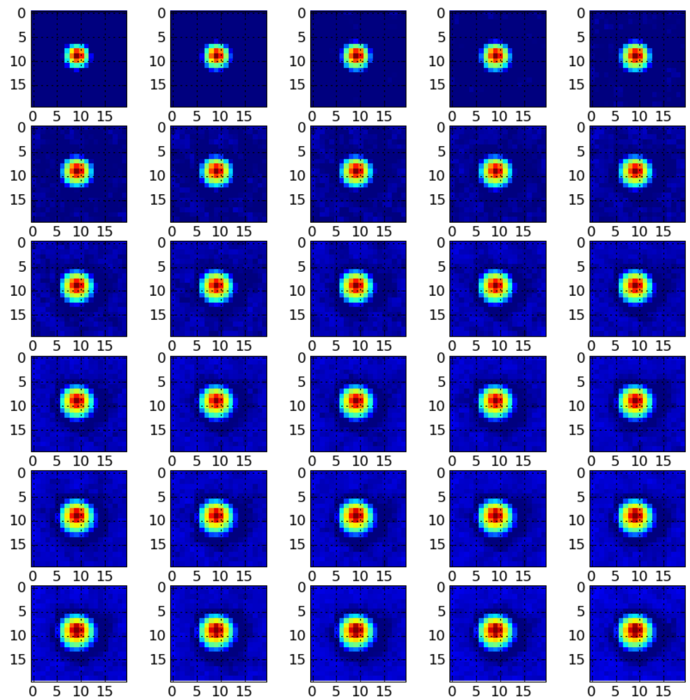


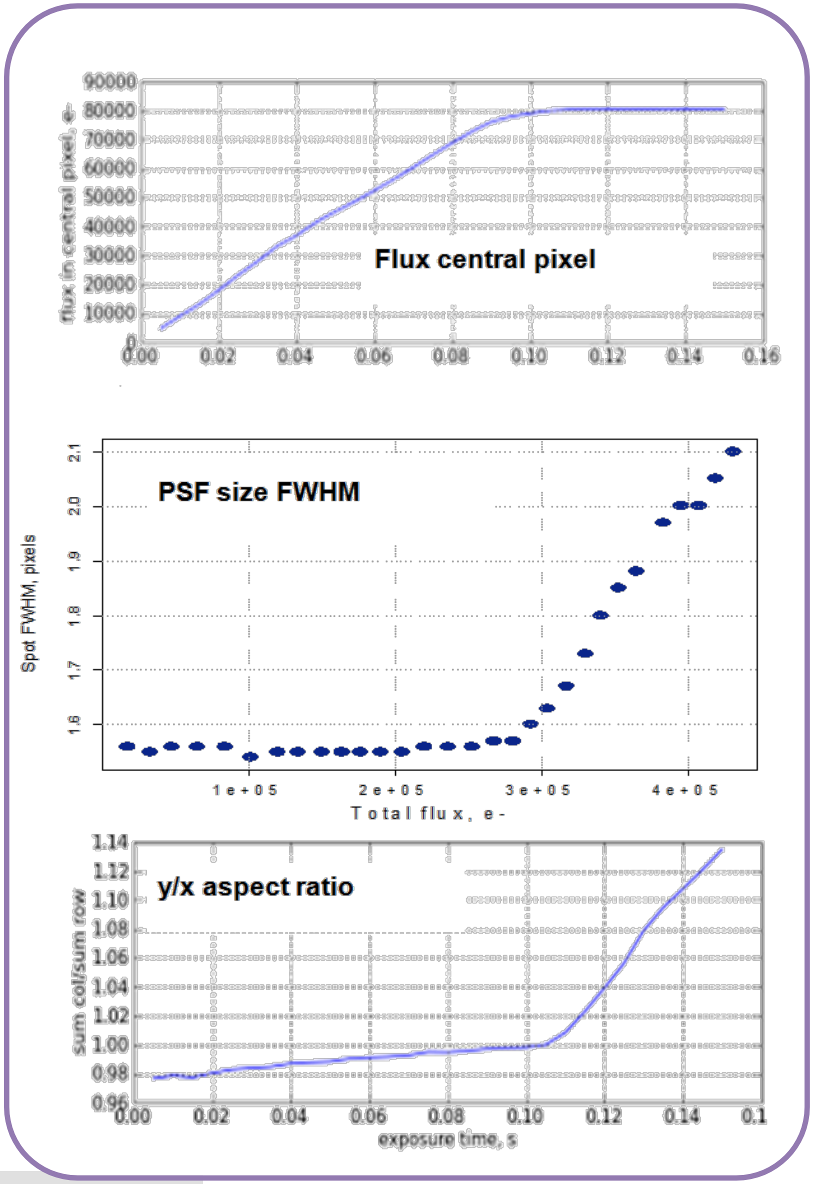
Spots and flat field behave differently

– due to space charge effects → similar to brighter-fatter effect

Intensity Dependence: Brighter-Fatter Effect

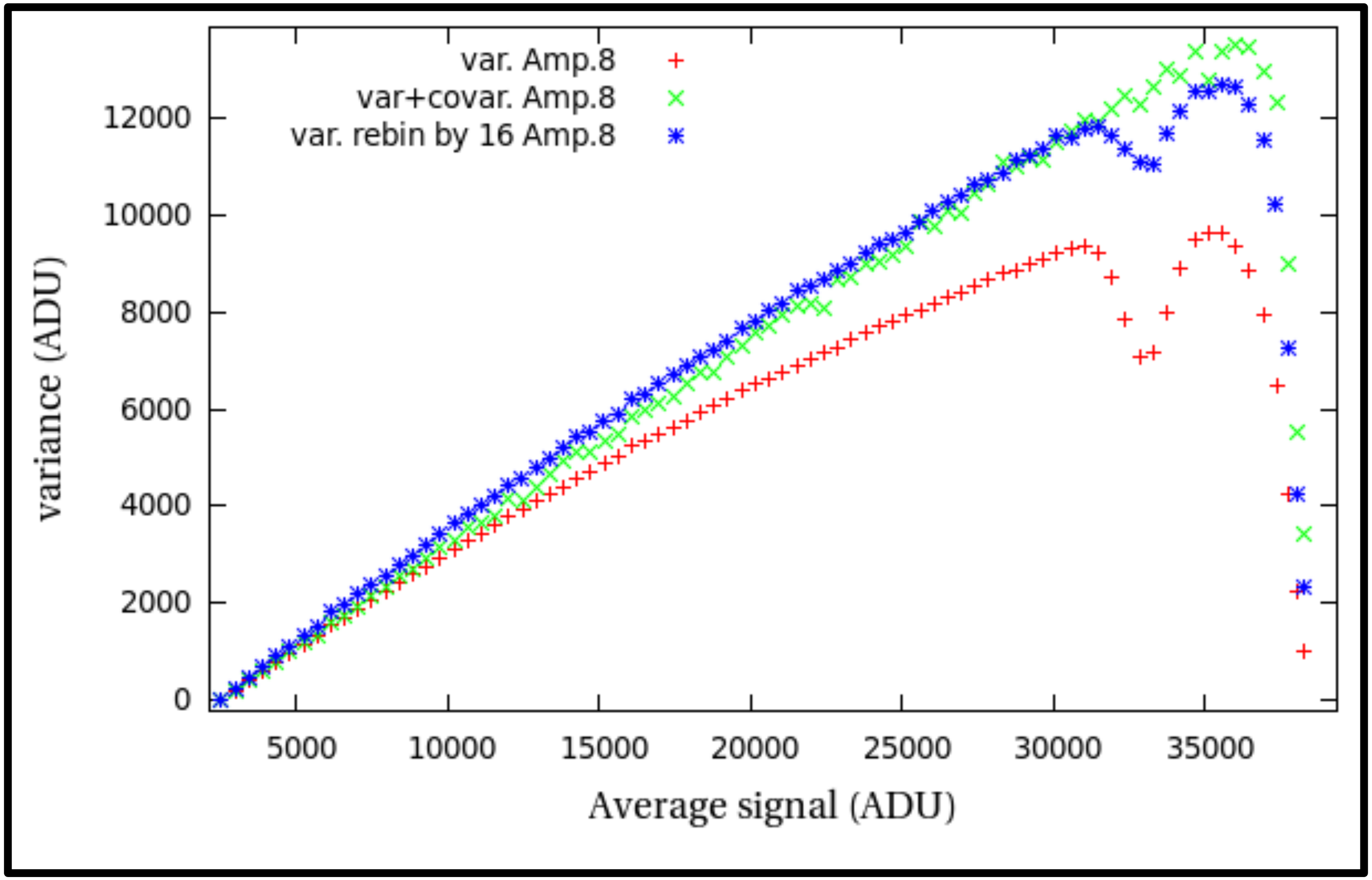






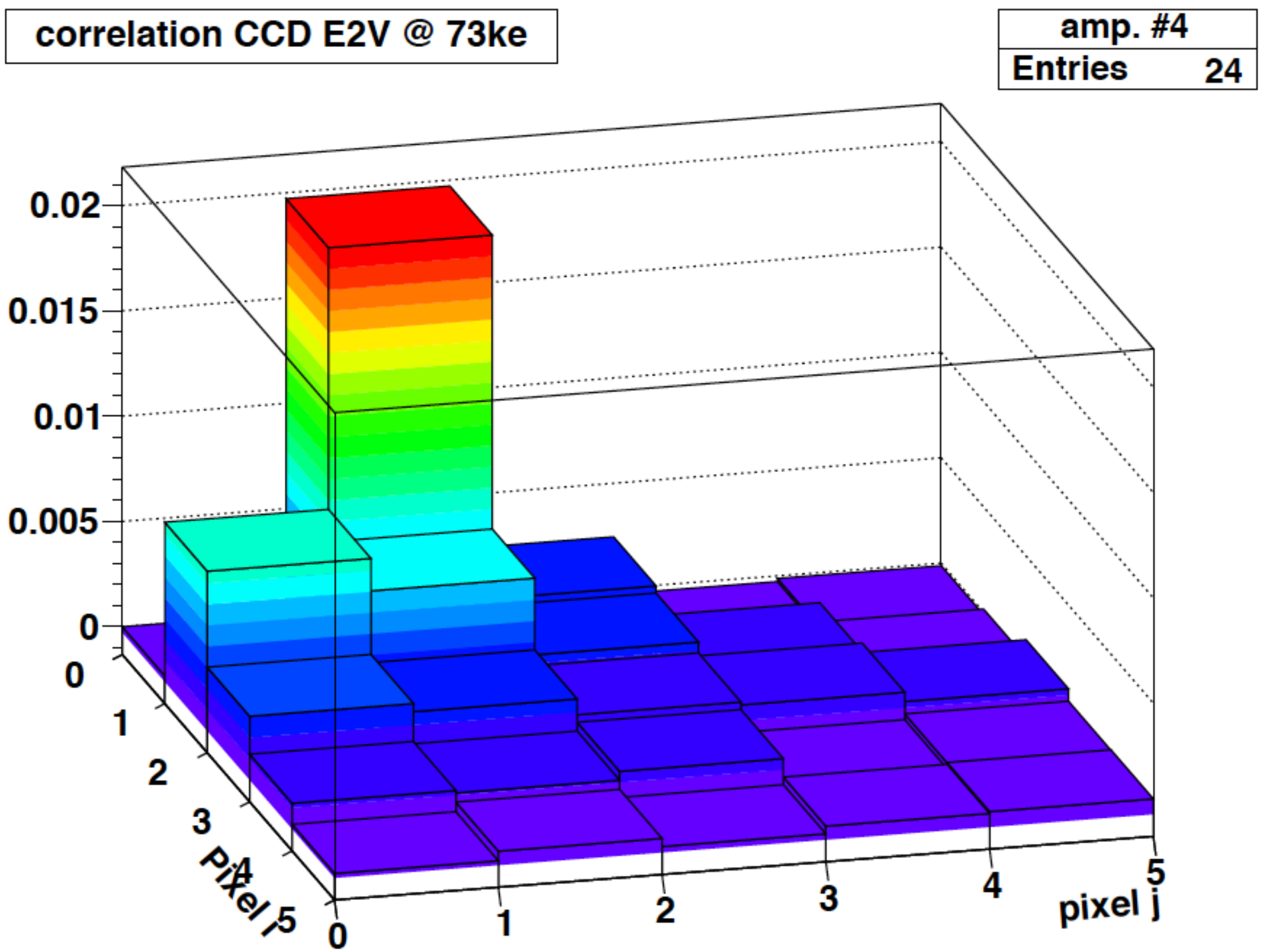
P.O'Connor

Charge smearing perturbs photon transfer curve



IN2P3 team, LSST sensor data

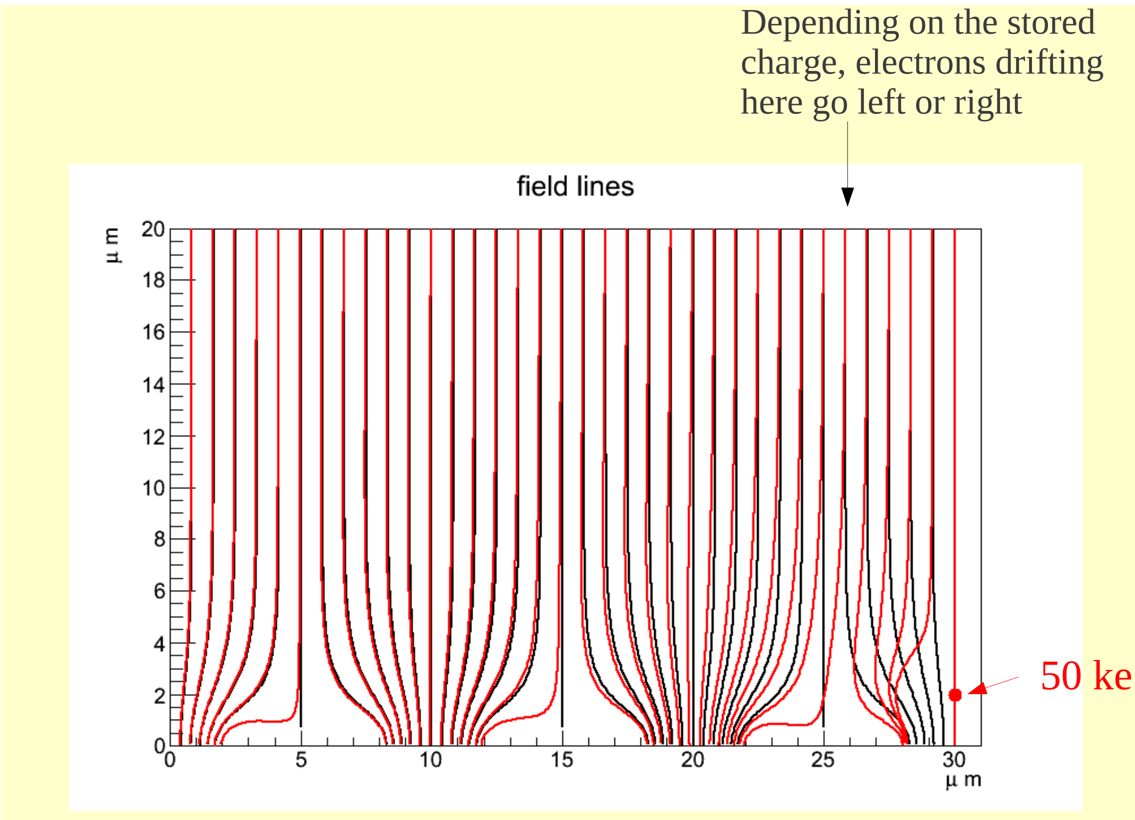
Signal Correlation in Neighbouring Pixels



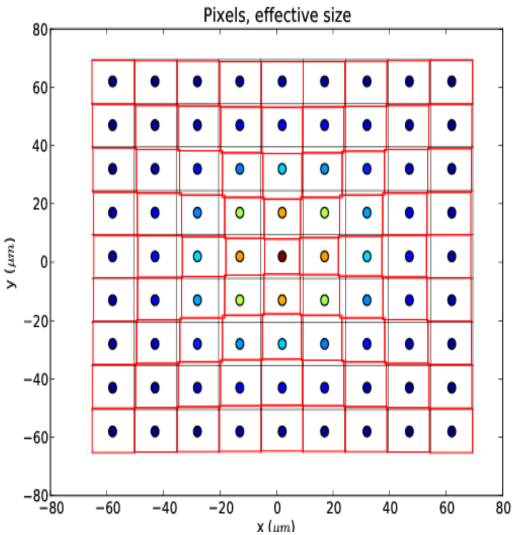
2-d autocorrelation at 73Ke, half of full well depth, (Harvard & IN2P3 analysis)

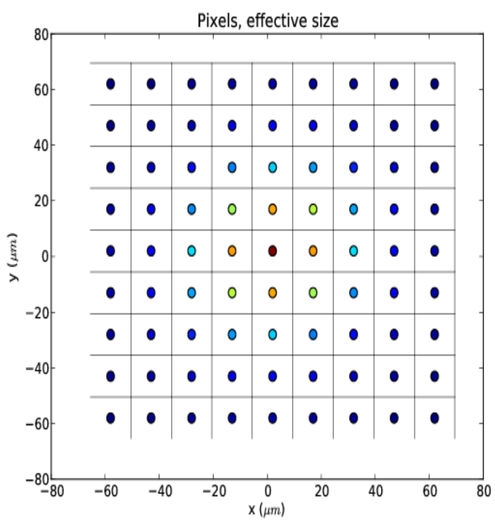
Brighter-Fatter Effect and Pixel Correlations

– Phenomenological approach using parameters from correlation matrices, can provide corrections



P.Astier





"Tree rings"

THE PRODUCTION AND AVAILABILITY OF HIGH RESISTIVITY SILICON FOR DETECTOR APPLICATION

Wilfried von AMMON and Heinz HERZER
Wacker-Chemitronic GmbH, 8263-Burghausen, Fed. Rep. Germany

Nuclear Instruments and Methods in Physics Research 226 (1984) 94–102
North-Holland, Amsterdam

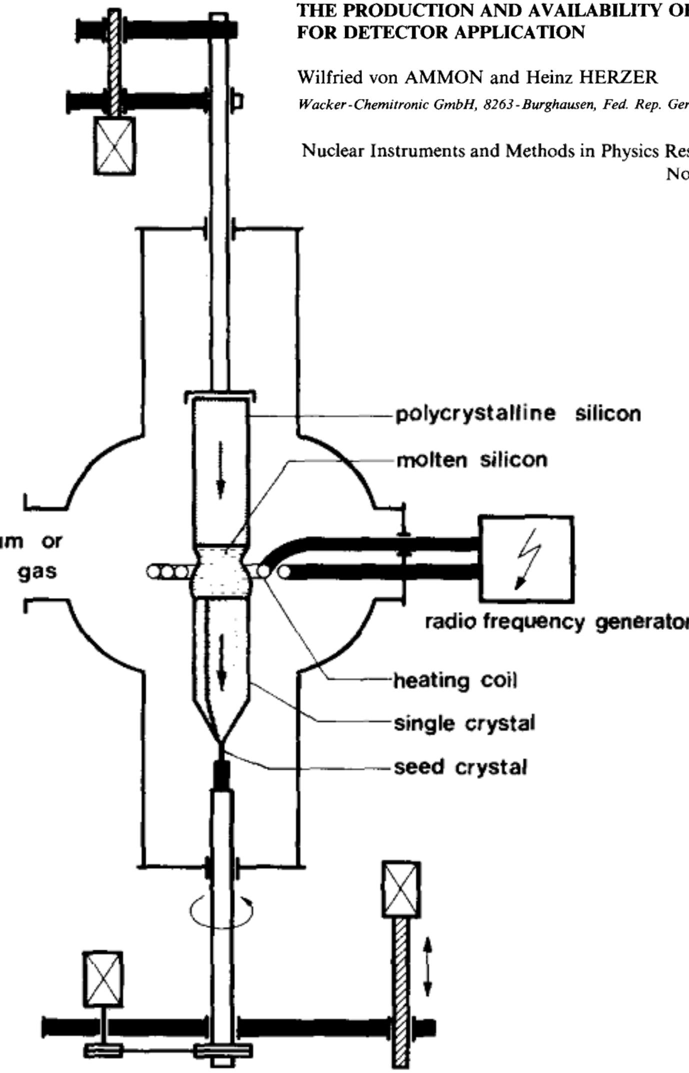


Fig. 4. Single crystal growth by the floating zone technique.

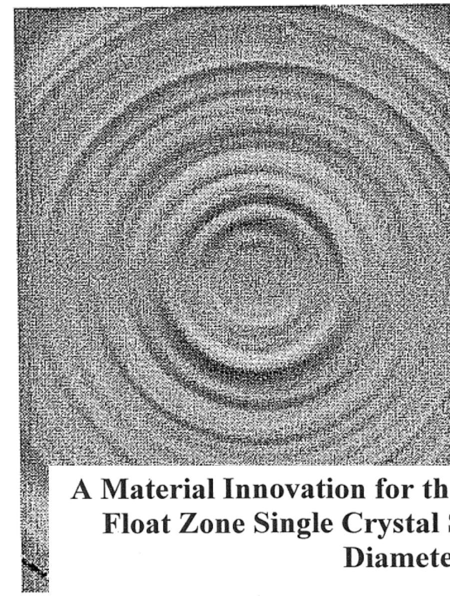
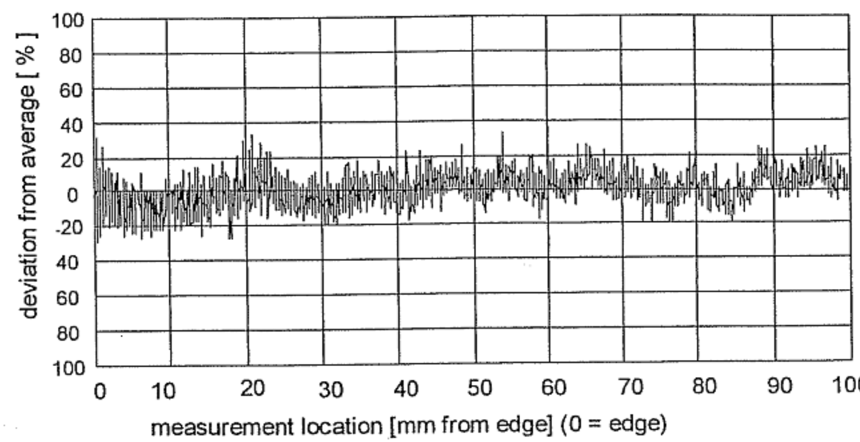


FIG.5) Photoscanning measurement on a wafer surface. The structure seen is the gradient of the resistance distribution.

A Material Innovation for the Electronic Industry: Float Zone Single Crystal Silicon with 200mm Diameter

L.Altmannshofer, M.Grundner, J.Virbulis, J.Hage
Wacker Siltronic AG, D-84489 Burghausen, Germany
e-mail: Manfred.Grundner@Wacker.com

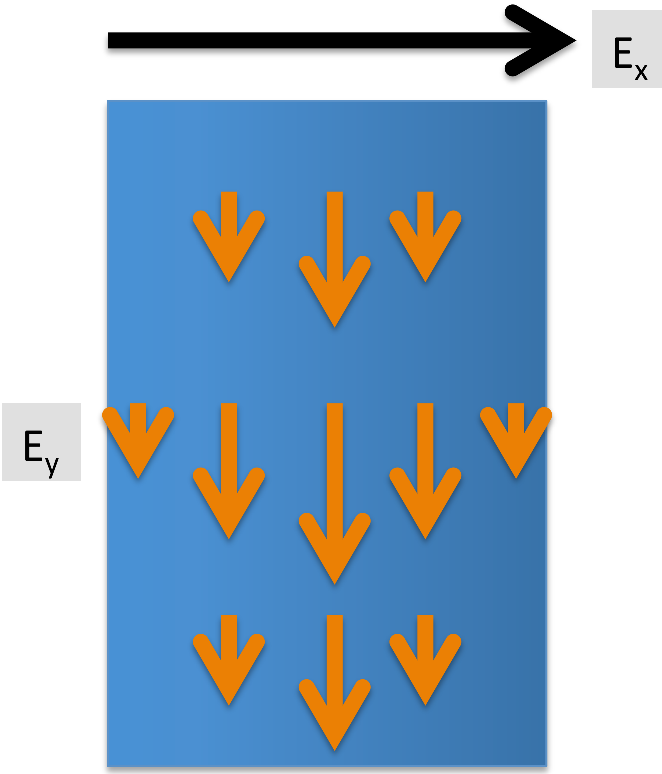


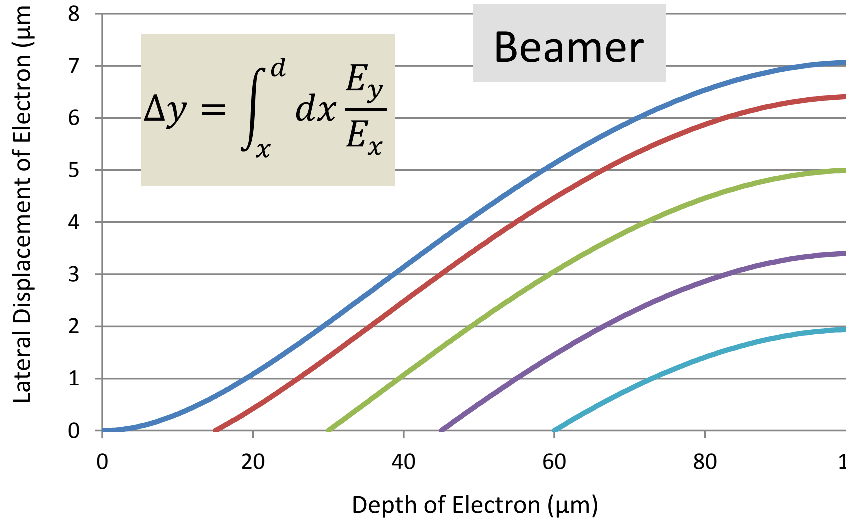
Tree rings arise due to resistivity variation

From S.Holland's talk at BNL workshop

17

Lateral E Field from tree rings





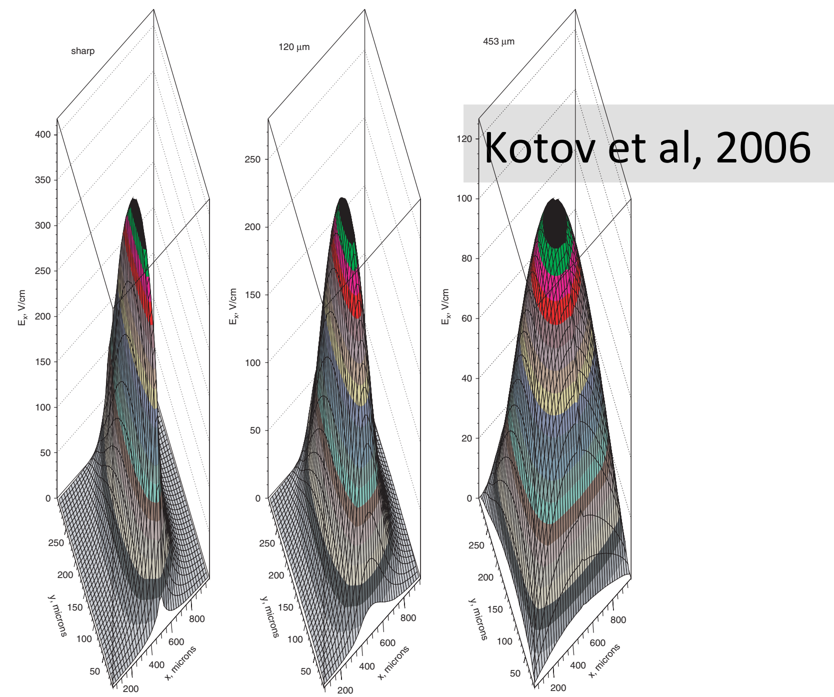
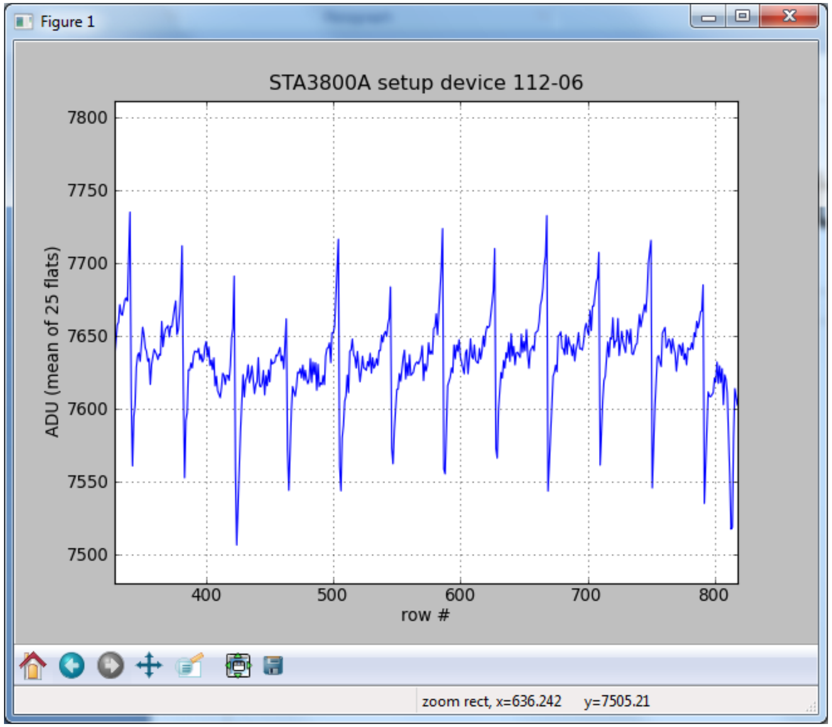
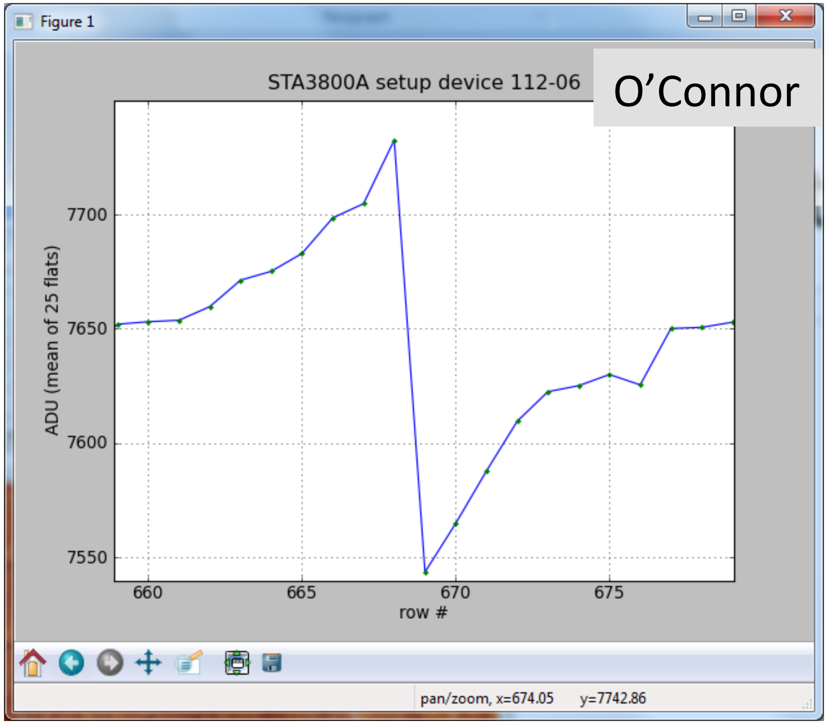


Fig. 3. The E_x component for "sharp" and Gaussian transitions of the doping profile.

Proper electrostatic simulations can be done but need to know sensor geometry/doping

LSST ITL sensors: 41st pixel structure



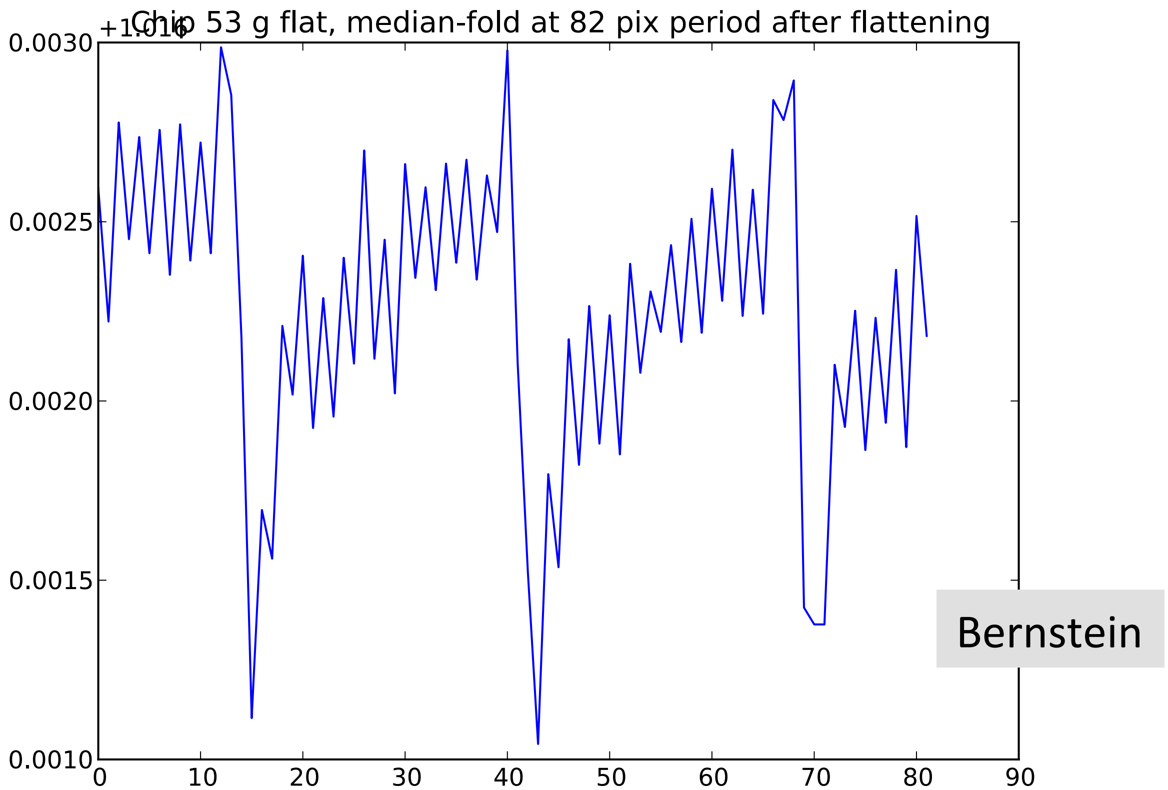


Pixel physical size distortions due to masks?

- Period 41 pixel x 10 micron = 410 micron
- DALSA used electron beam mask writer, could it be DAC differential non-linearity? Old sensors had laser-written mask and did not have this
- Weak dependence on bias, no wavelength dependence

Same effect in DES

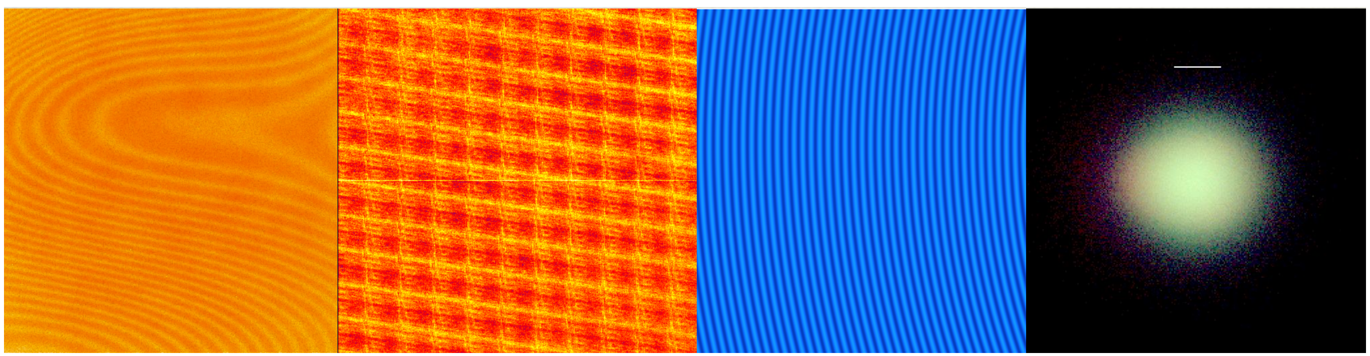
- Same vendor (DALSA)
- 27.333 pixel periodic modulation seen in dome flats
- 27.333 x 15 micron = 410 micron : same period as LSST
- Is it purely photometric?



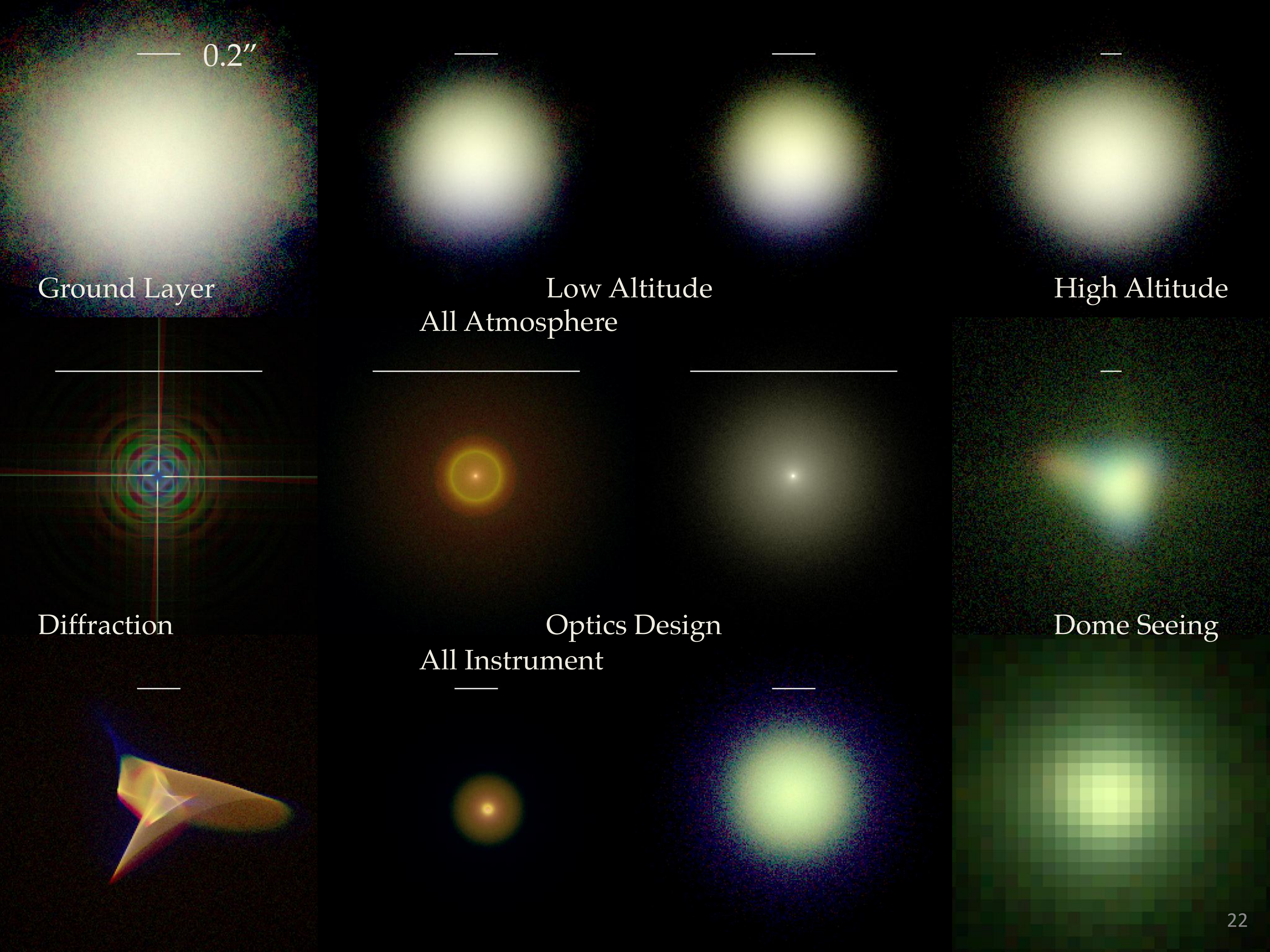
LSST: sensor simulations with Phosim

- Phosim (J.Peterson et al) : simulating telescopes one photon at a time
  - Instrumental effects include atmosphere, optics and sensors
- Good way to connect sensors to precision astrophysics

- Validate sensor part by simulations of lab setups and comparison to measurements
  - Most of sensor effects are now implemented in Phosim



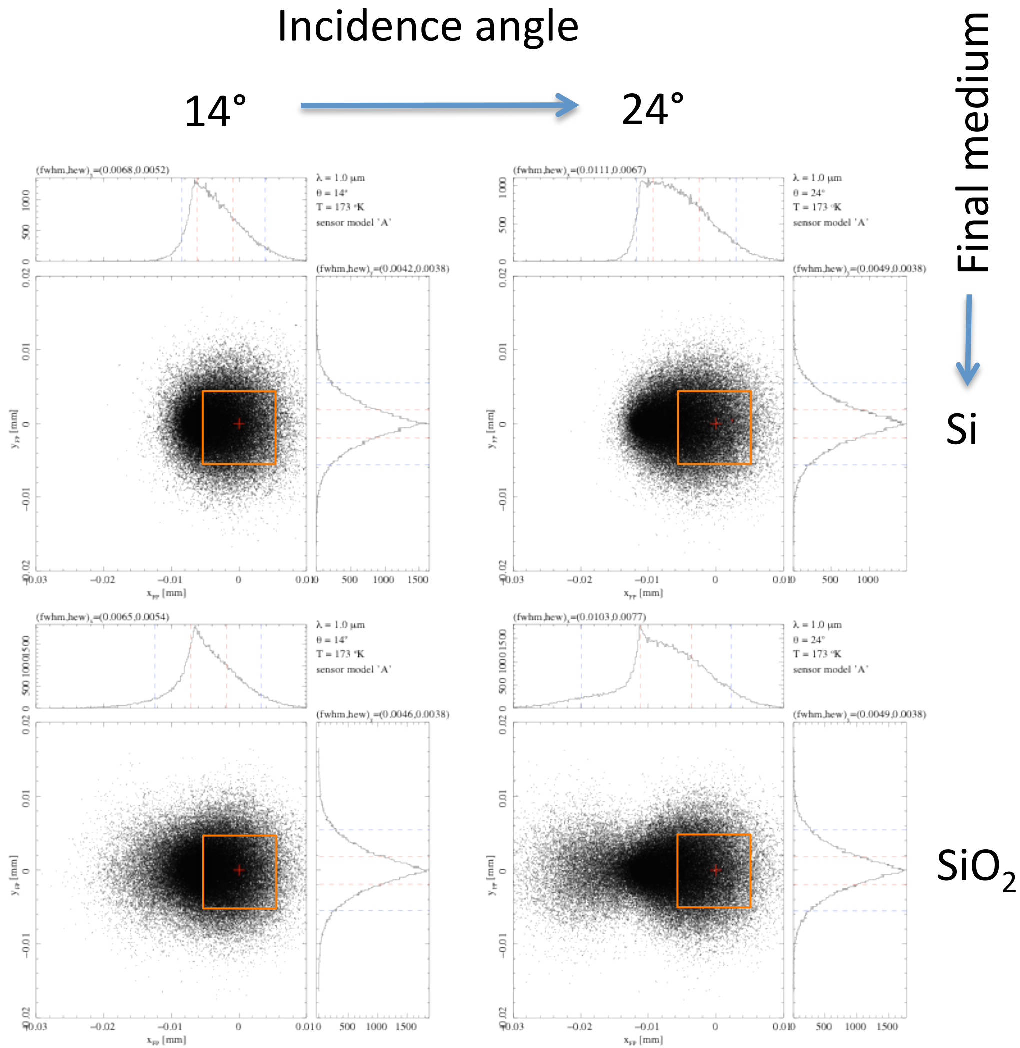
Use tuned simulations to evaluate sensor effects on science (can turn physics on/off)


0.2″
Ground Layer
Low Altitude
High Altitude
All Atmosphere
Diffraction
Optics Design
Dome Seeing
All Instrument

Modeling Charge Diffusion

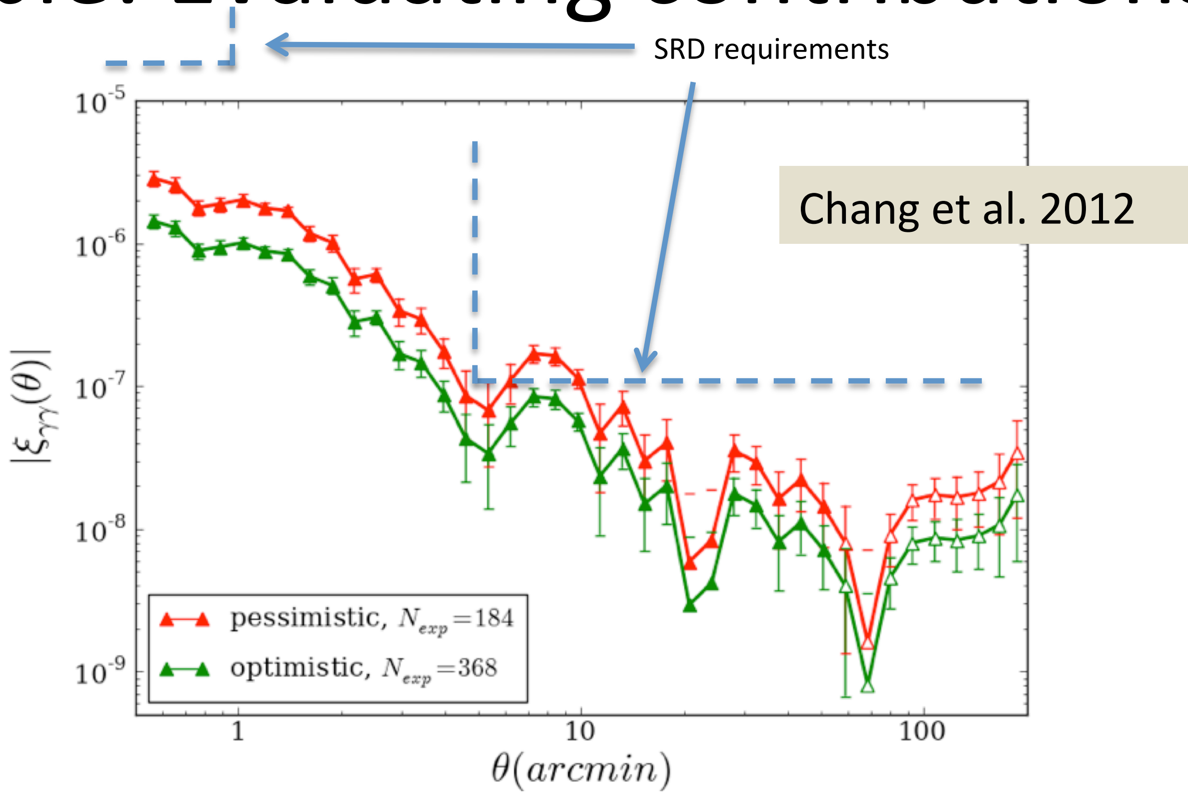
- Finite range in Si produces a skewed PSF that is fundamentally 3D and depends on interface properties

- PSF dependence on angle and interface for 1000nm



Rasmussen

Example: Evaluating contributions to shear

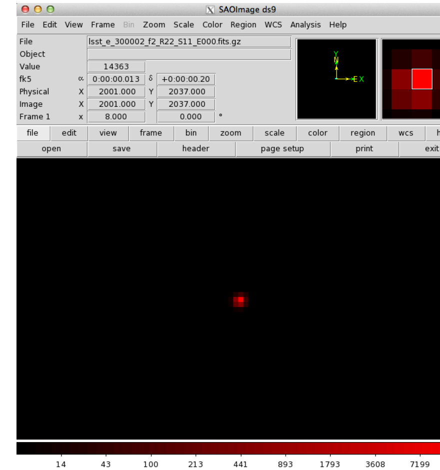


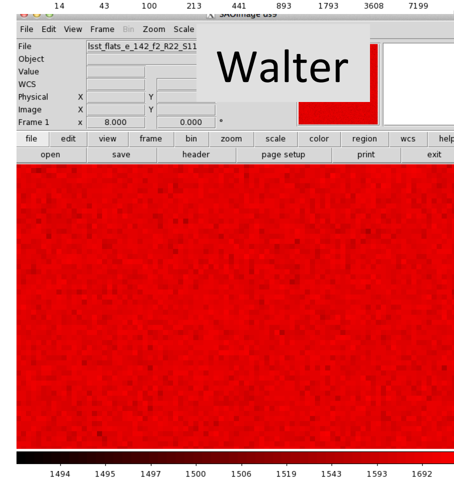
Absolute spurious shear correlation function after combining 10 years of r- and i-band LSST data; PSF knowledge from polynomial interpolation of stars

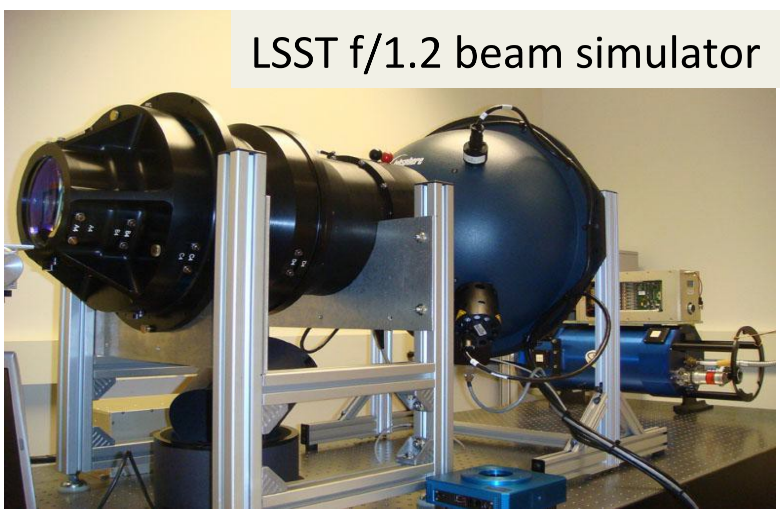
Requirements for weak lensing : shear correlation systematics are controlled to ~30% of the stochastic levels, or < 2×10^{-5} for θ<1’ and <1×10^{-7} for θ>5’.

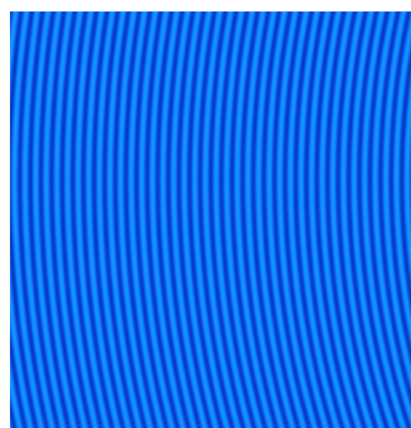
Current work on sensor effects in Phosim

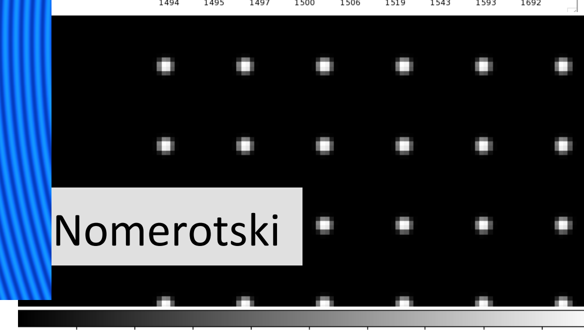
- Code development (J.Peterson et al)
- Brighter-Fatter effect
  - Validation of charge diffusion and charge sharing models
  - Correlations in simulated flats; Compare to data
- Tree rings
  - Tuning doping variations, code validation
- Description of lab setups at UC Davis (Tyson) and BNL











Summary

- Fully depleted CCD have a non-trivial electrostatics which lead to astrometric biases and PSF distortions (+ other important sensor effects)

- LSST has a comprehensive program to study these effects in the lab & simulations and their importance for science

Backups

Fringes

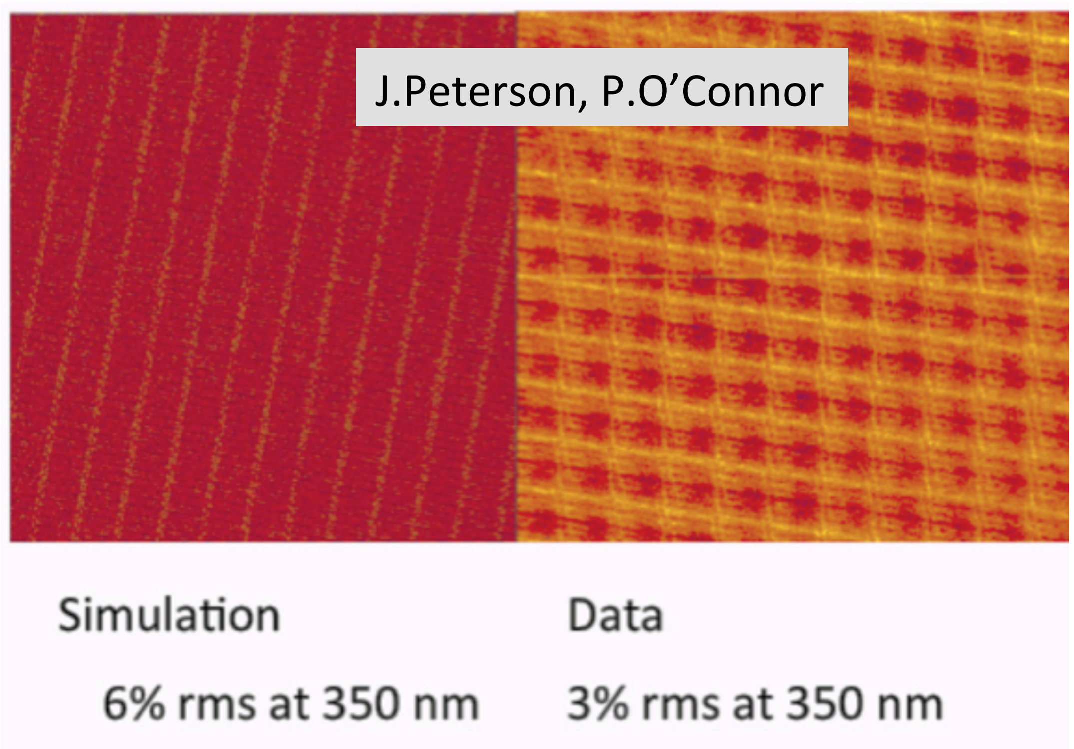
- Interference patterns due to reflections off the sensor bottom, visible at longer wavelengths
- Use a random surface with some flatness
- Will use BNL metrology data to validate
- Assumes that the backside is flat
  - Fringe data at different wavelengths should allow to extract the backside flatness

Simulation
0.4% rms

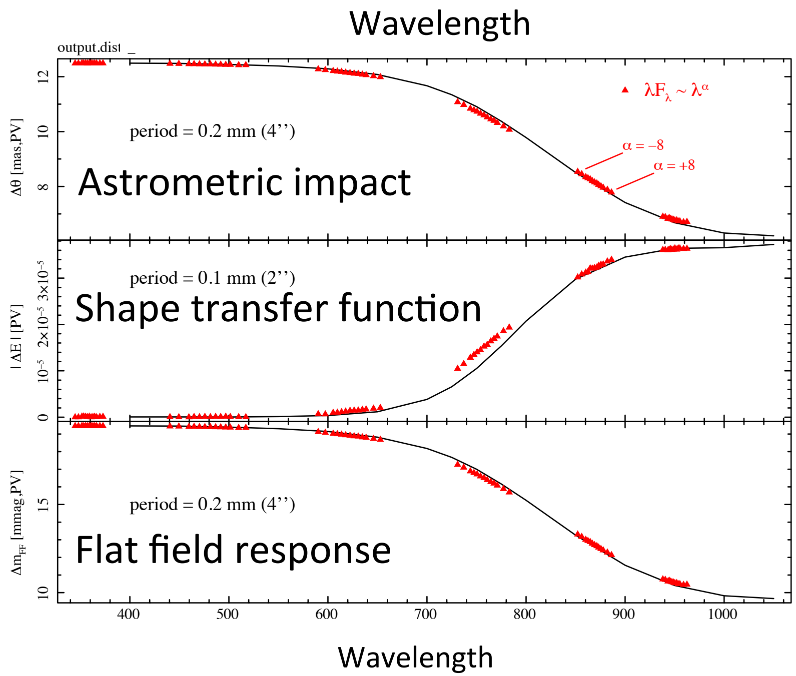
Data
1.2% rms w/ lab beam

Brick-wall pattern

- From laser annealing of back side, visible at short wavelength
- Described in PhoSim with 11 parameters
- Needs tuning



Tree Ring Impact



Rasmussen